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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

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☐ *Additional inventors are being named on the _____ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

HIGH POWER/WEIGHT RATIO BRAKING DEVICE BASED ON SHAPE MEMORY MATERIAL TECHNOLOGY

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☒ Specification *Number of Pages* 10 ☐ CD(s), Number

☒ Drawing(s) *Number of Sheets* 6 ☐ Other (specify)

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☒ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fees

☒ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number 150633

☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($) $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE

Date 04/17/2003

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Docket Number: 0058.003-P-US

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

60463339 .041703

HIGH POWER/WEIGHT RATIO BRAKING DEVICE BASED ON SHAPE MEMORY MATERIAL TECHNOLOGY

FIELD OF THE INVENTION

[0001] The invention relates to dry-friction brakes.

BACKGROUND OF THE INVENTION

[0002] When it comes to slowing down or completely stopping the rotation of a mechanical system, different braking strategies are being used. The most common brake technologies are: viscous brakes, hydrodynamic brakes where a fluid is forced to pass through a flow restriction orifice, magnetorheological brakes where a particular fluid changes its viscosity under the application of a variable magnetic field, electromagnetic brakes where a force opposing the rotation of a system is set up by inducing eddy currents within a metal disc inserted between two electromagnets, and dry-friction brakes where two surfaces are pressed one against the other.

[0003] Dry-friction brakes come in many types of configurations and are set apart by the shape of their friction surfaces and the nature of their activation principle. There are six main types of friction brakes, namely drum brakes, disc brakes, belt brakes, electromechanical and electromechanical power off brakes and magnetic particles brakes. Drum brakes consists of a flat-topped cylinder on which one or more brake shoes are pressed when the brakes are activated. Friction of the shoe on the drum surface slows down the rotation of the system. Disk brakes use a clamping action to produce friction between a disc and two pads mounted in a caliper. Disc brakes use a principle similar to the brakes on a bicycle; as the caliper pinches the disc with the pads on both sides, it slows down the system. Finally, belt brakes consist of a friction belt wrapped around a drum. The tension in the belt is proportional to the gripping force between the belt and drum, thus increasing this tension slows down the rotation of the drum. All these dry-friction brakes may either be hydraulically, pneumatically or electrically

activated as long as the selected activation principle ensures adequate functioning of the mobile brake element (shoe, pads or belt).

[0004] Electromechanical brakes operate via an electric actuation, but transmit torque mechanically. When voltage is applied to the brake, a coil is energized creating a magnetic field, which turns the coil into an electromagnet. The resulting magnetic flux attracts an armature that is brought into contact with friction pads. Since the armature is fixed relative to the shaft and the pads are fixed relative to the frame, activation of the brake slows down the rotation of the system. In most designs, springs hold the armature away from the brake surface when power is released. Conversely, in some designs, a series of springs force the armature in contact with the brake surface when no power is applied to it. These brakes, called electromechanical power off brakes, are released by applying voltage to a coil, which pushes the armature away from the brake surface. Another type of brakes, magnetic particle brakes, are located in a cavity where they simply lay when no power is applied. However, as soon as voltage is applied to a coil located on top of the cavity, the magnetic flux created tends to bind the particles together. As the voltage is increased, binding of the particles becomes stronger. Since the brake rotor passes through these bounded particles, the resistance force created on the rotor slows down the rotation of the system.

[0005] In the field of prosthetics, several types of brakes have been used in the past, each having their benefits and drawbacks.

[0006] Viscous brakes are well suited for prosthetic applications but are subject to leakage and failure under high loading conditions. On another hand their relatively high weight makes them less interesting compared to other solutions.

[0007] Magnetorheological fluids are theoretically suitable for applications where the viscosity of the braking device needs to be rapidly and accurately modified. However, practical applications shown that this viscosity changing is

not rapid and accurate enough to achieve acceptable performances in the field of prosthetics. Moreover, like the viscous brakes, their relatively high weight is detrimental to their selection in applications where dynamic braking is not a requirement.

[0008] Dry-friction brakes are not recommended for dynamic braking applications since the contact surfaces friction coefficient tends to change after extended use. However, their simplicity, compactness and lightness make them an interesting choice whenever dynamic braking is not necessary.

[0009] Furthermore, all braking devices presented above have a common limitation in that they require power to remain activated or inactivated.

[0010] Accordingly, it is an object of the present application to obviate or mitigate the above disadvantages.

SUMMARY OF THE INVENTION

[0011] The present invention seeks to provide a braking device that exhibits the ability to maintain a given state of activation when no power is supplied to it. This device takes advantage of some particular characteristic of shape memory alloys (SMA), namely the shape memory effect. The SMA brake is to be packaged on a leg prosthesis for above knee amputees but is not restricted to this specific application. It suits any general application where a braking torque needs to be applied to a rotational system.

[0012] In accordance with one aspect of the present invention, there is provided a set of Nitinol© wires positioned, in an agonistic-antagonistic configuration on each side of a brake lever. Braking and releasing phases are dictated by the austenitic transformation of the Nitinol© wires. During brake activation, shrinking of the braking wires brings the friction pad in contact with a rotating drum creating a braking friction torque. Once the brake has been activated, deformation of a flexible fiberglass component prevents brake releasing

by applying sufficient normal force between the drum and the friction pad. Conversely, upon heating of the releasing wires, the pad looses its grip and the drum is free to rotate.

[0013] Half of the Nitinol© wires are used for brake activation while the remaining is used for brake releasing. Brake amplification factor is determined by the position of the lever pivot. As much as possible, aluminum 6061-T6 is used as bulk material for weight reduction purposes. In order to increase the brake coefficient of friction, aluminum-bronze and steel are used for braking pad and drum manufacturing respectively. It is estimated that a 5V – 50A power supply is suitable for brake activation and releasing according to the SMA brake specifications.

[0014] Other features and advantages of the present invention will be more readily apparent from the following detailed description, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE FIGURES

[0015] FIG. 1 is a partially exploded view of the SMA brake concept.

[0016] FIG. 2 is a free body diagram of the SMA brake in activated state.

[0017] FIG. 3 is a deformation analysis of the fiberglass beam in activated state.

[0018] FIG. 4 is a trigonometric analysis of the brake pad displacement corresponding to minimal clearance in released state.

[0019] FIG. 5 is a free body diagram of the fiberglass beam.

DETAILED DESCRIPTION

[0020] In general, the invention fits any application where a braking torque needs to be either applied or released from a mechanical system in rotation, even

when no power is supplied to it. The invention requires power input only to change its state from activated to inactivated and vice-versa. The invention will be described by way of a particular embodiment describing an example application in which the invention provides emergency braking on a motorized prosthesis in case of power failure and power shut down. The invention does so by taking advantage of some particular characteristic of shape memory alloys (SMA), namely the shape memory effect. In this example application, the brake disclosed by the particular embodiment must:

[0021] 1. Be active at power failure or shut down, i.e. the brake will remain in position after activation or releasing even if no power is supplied to it.

[0022] 2. Withstand static load of the amputee when standing on one leg, i.e. the brake will produce a minimal torque of 2.2Nm when activated.

[0023] 3. Completely block the prosthesis as quickly as possible, i.e. the brake will block the prosthesis in less than 100ms and will be released in less than 2s.

[0024] 4. Be electrically activated, i.e. the brake will be adapted to a commercially available power supply.

[0025] 5. Respect specific security constraints, i.e. the brake will operate in a temperature range defined between –20°C and 40°C, the temperature of the SMA elements will never exceed 150°C and brake lifespan will be 100 000 cycles.

[0026] 6. Respect specific mass and volume constraints, i.e. the brake, excluding the power supply, will not weigh over 500g and will not exceed the volume of a 60mm-diameter and 60mm-long cylinder.

[0027] **OVERVIEW OF THE SMA BRAKE**

[0028] The SMA brake (10), as illustrated in FIG. 1, is composed of six main groups of components: the braking drum, the friction pad, the brake lever, the

fibreglass beam, the SMA elements and the frame. Engineering calculation associated with the selection and dimensioning of each component or group of components are included in the following sections. It should be noted that although the dimensions are in view of the example application, the same engineering calculation may be applied to other applications, which may have different dimensions.

[0029] **BRAKING DRUM**

[0030] Drum rotational inertia is a major concern since it affects the dynamics of the prosthesis, or whatsoever device the brake is mounted on. In in order to keep this parameter as low as possible, the braking drum core's (19) maximal diameter is fixed to 23mm and the recommended material is aluminum 6061-T6. In order to improve the coefficient of friction between the braking drum and the friction pad (17), a 1mm-thick steel braking sleeve (18) is press-fitted on the drum core (19).

[0031] **FRICTION PAD**

[0032] In order to get high friction coefficient and high heat dissipation properties, aluminum-bronze is preferably used as raw material for the friction pad (17). Static coefficient of friction between aluminum-bronze and steel is estimated to 0.3. Considering this value and the short-shoe friction brake illustrated in FIG. 2 and described by Equation 1, the normal force between the braking sleeve (18) and friction pad (17) needed to provide a 2.2Nm braking torque on a 25mm diameter drum is estimated to 587N.

$$N = \frac{T}{\mu r} \qquad \text{Equation 1}$$

[0033] **BRAKE LEVER**

[0034] The brake amplification factor is directly related to the position of the lever pivot point. Considering the recommended stress applied to Nitinol© wires in martensitic state (20MPa), the cross-sectional area of those wires ($0.78mm^2$) and the normal force estimated above (587N), the amplification factor of the brake is evaluated to $X = 12.5$.

[0035] Equation 2, Equation 3 and Equation 4 are obtained from FIG. 2. Substituting Equation 2 and Equation 3 in Equation 4 and solving for *a*, the position of the pivot point is estimated to a = 13mm and b = 11mm.

$$X = \frac{(c^2 + d^2)^{1/2}}{b - \mu(a + r)} \qquad \text{Equation 2}$$

$$L^2 = c^2 + d^2 \qquad \text{Equation 3}$$

$$R^2 = a^2 + b^2 \qquad \text{Equation 4}$$

[0036] For weight reduction purposes, aluminum 6061-T6 is recommended as the bulk material for the manufacturing of the brake lever (15).

[0037] **FIBERGLASS BEAM**

[0038] S-Glass–Epoxy is preferably selected as the fiberglass beam (22) material since it exhibits a low Young's modulus/Tensile strength ratio. From FIG. 3 and Equation 5 and considering the properties of this material (E = 45GPa and S_u = 1000MPa), a recommended flexural stress σ_{max} = 300MPa, a maximal force at the extremity of the beam (22) $F = N/X$ = 46.9N and a 10mm-long and 10mm-wide beam (22), the minimal beam (22) thickness is estimated to h_{min} = 1mm. From FIG. 3 and Equation 6 and considering the same parameters, the deflection of the beam (22) extremity is estimated to Δ_{DD1} = 0.42mm.

$$h_{min} = \sqrt{\frac{6FW}{b\sigma_{max}}} \qquad \text{Equation 5}$$

$$\Delta_{DD_1} = \frac{4FW^3}{Ebh^3}$$ Equation 6

[0039] SMA ELEMENTS

[0040] Considering, Equation 7 and obtaining the displacement of brake lever extremity, *DD'* from FIG. 4. Considering the active strain of braking SMA elements (21), $\varepsilon_a = 4\%$, the elastic recovery strain of releasing SMA elements (12) under the application of F = 46.9N, $\varepsilon_{rec} = 0.07\%$ and the strain of braking SMA elements (21) under the same force, $\varepsilon = 0.5\%$, length of SMA elements (12, 21) is evaluated to L_{SMA} = 30mm.

$$\varepsilon_a L_{SMA} = DD' + \varepsilon_{rec} L_{SMA} + \Delta_{DD1} + \varepsilon L_{SMA}$$ Equation 7

[0041] Considering Equation 8, the volume of each SMA elements (12, 21) is estimated to V = 23.4mm^3, that is the total volume of braking SMA elements (21) and releasing SMA elements (12) is V_{TOT} = 70.2mm^3 each. From Equation 9 and considering the density of Nitinol©, ρ = 6450kg/m^3, the mass of each SMA elements (12, 21) is estimated to m = 1.51x10^{-4}kg, that is the total mass of braking SMA elements (21) and releasing SMA elements (12) is m_{TOT} = 4.53x10^{-4}kg each. Finally, from Equation 10 and considering the electrical resistivity of Nitinol©, ρ_{el} = 0.8μΩm and the three SMA elements (12, 21) on each side of the fiberglass beam (22) connected in series via steel SMA elements connectors (11), the electrical resistance of SMA elements (12, 21) is estimated to R_{el} = 0.092Ω.

$$V = AL$$ Equation 8

$$m = \rho V$$ Equation 9

$$R_{el} = \rho_{el}\frac{3L}{A}$$ Equation 10

[0042] Stress generated by the braking SMA elements (21) during brake activation is obtained from FIG. 5 and Equation 11. Considering F = 15.6N, W = 10mm, x = 6mm, A = 0.78mm^2 and σ_m = 100MPa, this parameter is estimated to σ_g = 80MPa. From Equation 12 and considering room temperature, T_{amb} = 25°C, Nitinol© transformation temperature, A_s = 70°C, Nitinol© stress gradient $d\sigma/dT$ = 5MPa/°C and the value of σ_g estimated above, total temperature elevation for brake activation is estimated to ΔT = 61°C.

$$\sigma_g = \frac{FW + \sigma_m Ax}{AW} \qquad \text{Equation 11}$$

$$\Delta T = \frac{1}{\sigma_g}\frac{d\sigma}{dT} + (A_s - T_{amb}) \qquad \text{Equation 12}$$

[0043] In a similar way, stress generated by the releasing SMA elements (12) during brake releasing is obtained from FIG. 6 and Equation 13. In this case, σ_g is estimated to 167MPa and the associated total SMA temperature elevation is estimated to ΔT = 78°C.

$$\sigma_g = \frac{\sigma_m x}{W} \qquad \text{Equation 13}$$

[0044] The energy required for brake activation or releasing is obtained from Equation 14. Considering the latent heat and transformation enthalpy of Nitinol©, c_p = 322J/kg°C and h_T = 24200J/kg, the mass of material, m = 4.53x10^{-4}kg and the temperature elevation values stated above, the energy associated with brake activation is, U_{act} = 19.9J, whereas the energy associated with brake releasing is, U_{rel} = 22.3J.

$$U = m(c_p \Delta T + h_T) \qquad \text{Equation 14}$$

[0045] From Equation 15 and considering the parameters evaluated above and the SMA brake functional requirements, the current required to activate the

brake in less than 100ms is estimated to I_{act} = 46.5A whereas the current required to release the brake in less than 2s is estimated to I_{rel} = 11A. From Equation 16 and considering the current values evaluated above, the voltage associated with brake activation is estimated to V_{act} = 4.3V whereas the voltage associated with brake releasing is estimated to V_{rel} = 1V.

$$I = \sqrt{\frac{U}{Rt}} \qquad \text{Equation 15}$$

$$V = RI \qquad \text{Equation 16}$$

[0046] FRAME

[0047] Components that remain fix relative to the prosthesis, or to whatsoever device the brake is mounted on, build up the frame. Those components are: the SMA inserts (14), the upper and lower SMA shafts (13, 20) and the lever pivot shaft (16). The SMA inserts (14) are made of HST II phenolic, a relatively rigid electrical insulator. The upper and lower SMA shafts are made of steel and are used to adjust the initial tension in SMA elements (12, 21). The steel lever pivot shaft (16) is positioned in such a way that the amplification factor of the brake is fixed to X = 12.5.

[0048] Although the present invention has been described by way of a particular embodiment thereof, it should be noted that modifications may be applied to the present particular embodiment without departing from the scope of the present invention.

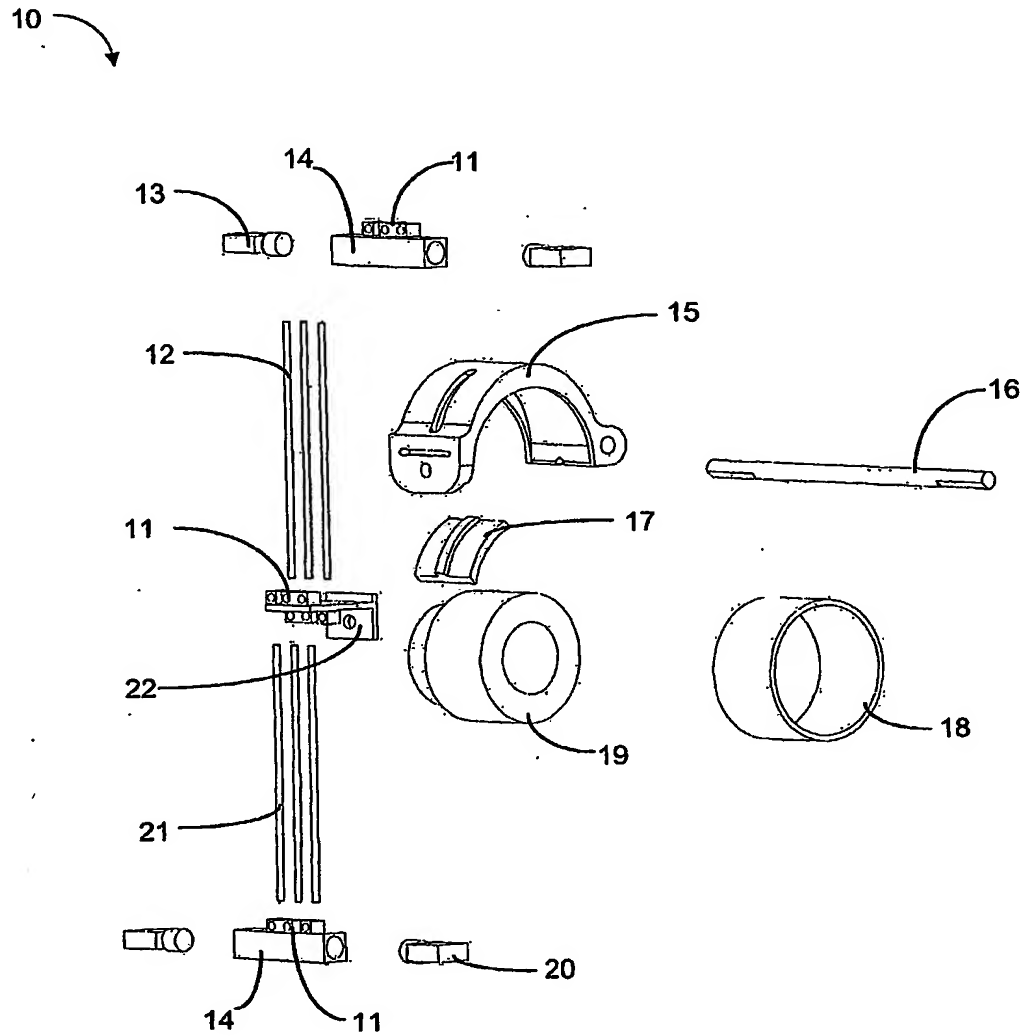


FIG. 1

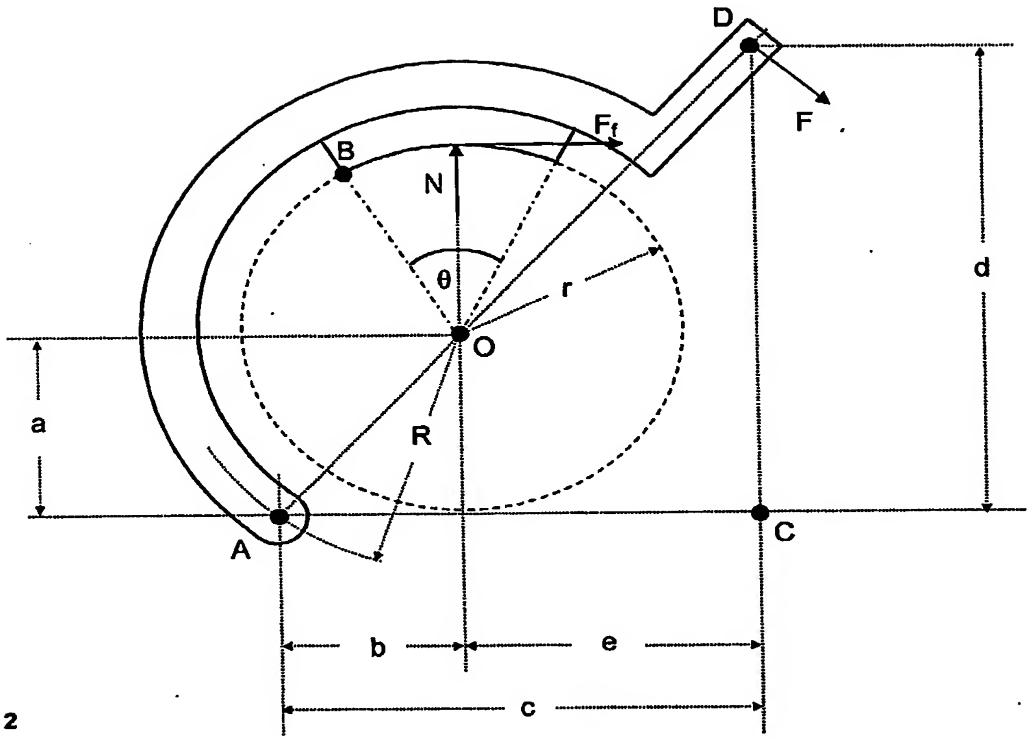


FIG. 2

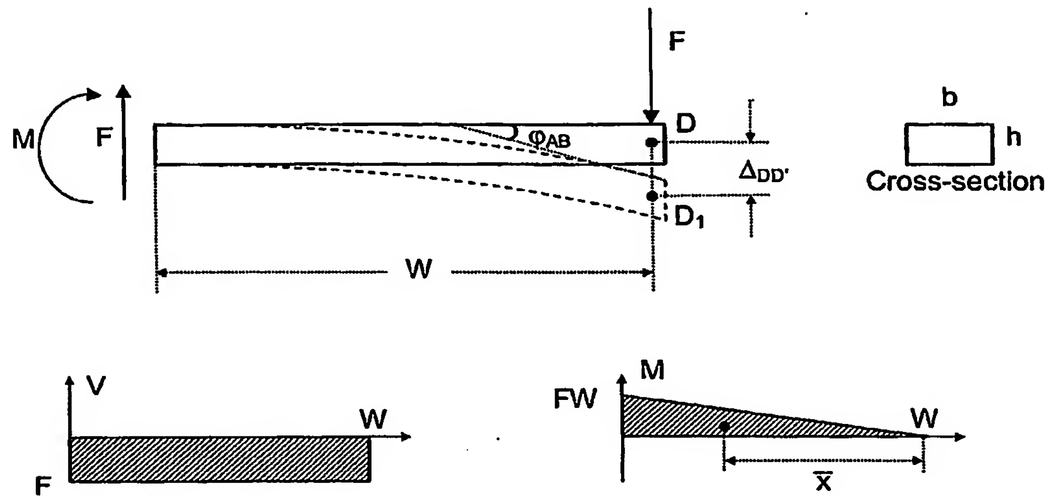


FIG.3

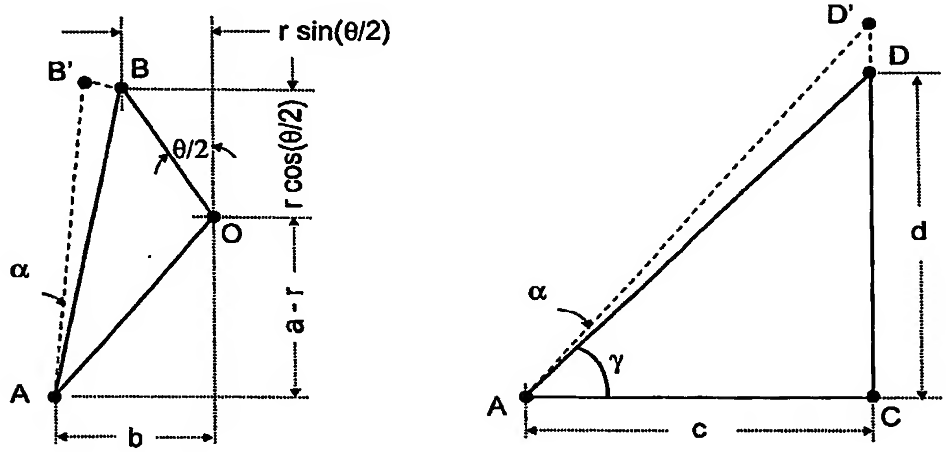


FIG. 4

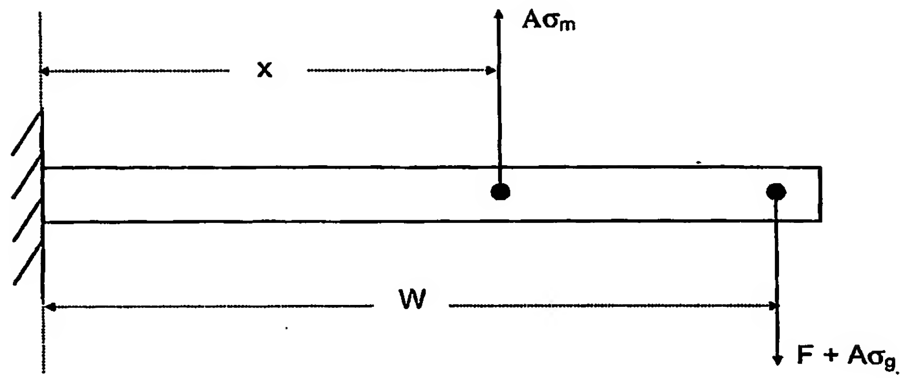
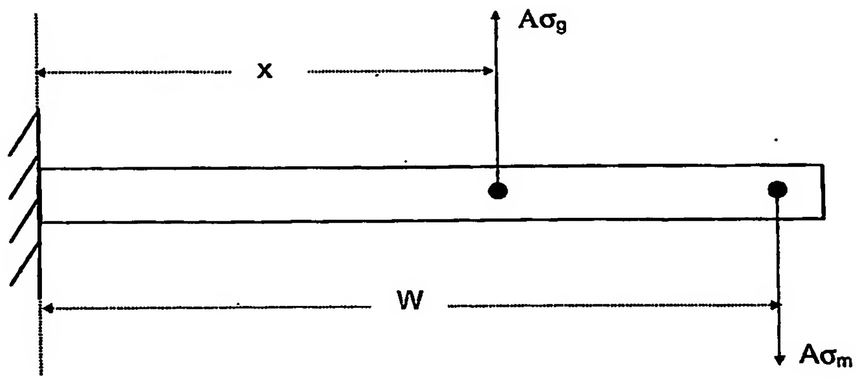


FIG. 5



i) FIG. 6